PB-217 605

DISPOSAL TO THE ENVIRONMENT

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Federal Water Pollution Control Administration
Cincinnati, Ohio

1968

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PB 217 605

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ROBERT B. DEAN*

ABSTRACT

Pollutants that are removed from wastewaters must be treated in such a way that they will not interfere with the intended use of the environment. The elements of polluting substances may be placed in the air, on or under the land, and in the oceans. Preliminary conversion to innocuous or nonextractable forms is necessary. Organic substances may be oxidized to CO_2, H_2O, and N_2 by dry incineration, wet oxidation at high temperature and pressure, or by soil organisms. Water-soluble salts must be locked up or diluted in the ocean. Most other elements should be buried as insoluble precipitates.

Calcium phosphate may be precipitated by 300 to 500 mg/l of lime as CaO along with $CaCO_3$, $Mg(OH)_2$, and heavy metals. $CaCO_3$ can be burned at 1800°F to recover CaO which is reusable even though it is contaminated with calcium phosphate, magnesium oxide, and "ash." Hard waters produce excess lime which must be wasted. In soft waters calcium phosphate accumulates in the lime with each reburning and may be recovered for sale. Aluminum hydroxide formed from alum or sodium aluminate removes phosphates at a 2:1 ratio of Al:P. Aluminate can be recovered at high pH and can be separated from phosphates by additions of lime.

The sign "Clean Water" appears on many publications of the Federal Water Pollution Control Administration. It is a goal that few would contest, at least as it applies to water that we get from the fellow upstream. But there is another way to read it, "We must go out and clean water!" "We" means all of us from the man in the boat to the largest factory, not omitting the federal installation. Cleaning water means to take the pollutants out of it, no matter how you clean water you end up with, water which you can use or add to the river, and with a residue of pollutants which have little or no value. It is the assignment of the Ultimate Disposal Research Activities of the Federal Water Pollution Control Administration to devise methods for treating these residues so that they will not pollute the environment.(1) The environment includes air and land as well as water. Thus, disposal of water pollutants by incineration must not lead to air pollution and, vice versa, wet scrubbing of furnace gases must not lead to water pollution.

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(1)Superior numbers in parentheses denote references cited.

DISPOSAL SITES

There are only three places where it is practical to dispose of polluting substances after they have been rendered innocuous: air, land, or oceans. Surface waters are not available for disposal. With the exception of water itself there are no substances which can be disposed of in large quantities into fresh water without causing pollution of some sort.

Before disposal it is ordinarily necessary to render innocuous the substances which have been removed from

wastewater. This can be done by dilution, as brines from desalting plants are disposed of in the ocean, by locking up, as insoluble salts in impermeable caskets, or by chemical conversion to less objectionable substances. In some cases chemical conversion can produce salable products which may help to defray the cost of treatment.

Spreading of liquid sludges on the surface of the land is one of the oldest and least expensive methods of sewage sludge disposal.[2] Early applications of untreated sludge in an uncontrolled manner produced bad odors and foul seepage to streams and therefore this method is not favored. However, land spreading is by far the cheapest way for dewatering sludges, and work is being done to improve the process. Spreading of soluble salts or toxic metals is unsuitable, but most soils have great capacities for dewatering and oxidizing organic matter. The fertilizer value of sludge, in terms of nitrogen, phosphorus, and potassium, is very low in comparison with synthetic fertilizers, and attempts to market dried sludge for fertilizer have usually failed to show a profit. In many areas farmers are glad to have wet sludge spread on their fields, and rivalry among farmers to get the wet sludge may eventually give it a market value.[3] Typically, the sludge is spread in a thin layer from a tank truck or is sprayed from a large nozzle; puddling is avoided to minimize odors. If the soil is plowed frequently, soils can assimilate and oxidize almost unlimited quantities of dried sludge. The toxicity caused by excessive loadings of sludge in some areas has been attributed to a high content of heavy metals, especially copper and zinc.

Some form of digestion or stabilization is required before sludge can be applied to the land. The sludge for sale on the retail market is dried and heat-sterilized. Air-dried sludges are given away to farmers and greenskeepers all over the country. Anaerobically digested sludge is being spread wet in many areas. A trend toward producing aerobically stabilized or digested sludge has been noted, particularly in smaller treatment plants. Dalton and others[4] in Chicago have proposed a pipeline to transport sludge to low-quality land in Cook County, and ultimately to land 50 miles south of the city. Morgantown, West Virginia, has a grant to pipe sludges five miles to a strip mine spoil area, according to *Engineering News Record*.[5] In both cases local opposition to dumping of sewage "in our backyard" has developed.

Deep-well disposal is attractive for soluble wastes such as salt solutions if the underground formation is suitable.[6] The largest scale application of this method is the return of salt brines from petroleum recovery. Most underground aquifers act as filters, and there is great danger that the pores will be clogged if suspended solids are present in the fluid. Water can also be introduced underground at high pressure which fractures the rock formation and opens up bedding planes. Here the formations will admit some suspended solids. Whenever water is placed underground there is danger of eventual pollution of nearby ground water. Changes in surface levels and earthquakes have also been attributed to underground injection of wastes.[7]

The costs of mined cavities, such as those used for underground storage of fuel gas, are high compared with other routes for ultimate disposal. They are more suitable for disposal of radioactive wastes which require continued monitoring. Very large cavities produced by nuclear explosions might be utilized if the geology were favorable.[8]

SPECIFIC POLLUTANTS

A rational analysis of ultimate disposal problems must start with the chemistry of the pollutants. Since polluting substances can be chemically transformed into less obnoxious forms, we should start with the individual elements. Fortunately, we do not have to consider 100 different elements because the majority are so rare that they do not constitute pollution problems, except for occasional accidents. Disposal of radioactive isotopes is not included since the use and disposal of these materials is subject to strict control by the U. S. Atomic Energy Commission. Figure 1 shows those elements which constitute over 99 percent of the ultimate disposal problems.

ORGANIC SLUDGES

The largest disposal problem facing municipal treatment plants is undoubtedly organic matter. Organic substances are compounds of carbon with

hydrogen, oxygen, and lesser amounts of nitrogen, sulfur, and phosphorus, together with other elements which can be lumped together as ash. The principal problem in the disposal of organic matter is, however, not the carbon compounds but the associated water. A 5 percent primary sludge on a dry weight basis contains nearly twenty times as much water as all other matter. Waste activated sludge may be concentrated by settling to 2 percent solids and at this concentration it contains over 50 times as much water as organic matter. The removal of water by sedimentation and filtration is dealt with in other places. It is obviously not economical to use fuel to dry sludge beyond the point where it will support its own combustion.

The ultimate form for disposal of organic substances is oxidation to carbon dioxide (CO_2) and water. All organic matter in sewage was derived initially from CO_2 in the air and its return represents a very small fraction of the daily contributions from the combustion of fuels. Carbon monoxide can easily be eliminated by proper furnace design. In practice sludge that is to be incinerated will be dried only enough to permit it to support combustion. Since the principal costs seem to lie in the filtering and drying stages, an economic balance requires a study of the entire system.

PHOSPHATES

Phosphates are the greatest uncontrolled pollutant in wastewaters today. Orthophosphate is a prime nutrient for algal growth in surface waters, and present-day treatment removes only a fraction of the phosphate load in the form of organic sludges. Phosphorus occurs in at least three forms in raw sewage: ortho, condensed, and organic phosphate; normal biological treatment hydrolyzes over 95 percent to orthophosphate, $HPO_4^=$ and $H_2PO_4^-$, in secondary effluents.

Under certain conditions which are still not understood, activated sludges can accumulate a large fraction of the phosphate present in wastewater.(9) Studies are underway to maximize this process since it could become a low-cost way of removing phosphates. The phosphates accumulated by active sludge can easily be lost by relatively short anaerobic periods, and a large fraction of the phosphates are redissolved in digester supernatants.(10) If this supernatant is returned to the head of the plant, it adds to the phosphate load to be handled. Incineration of sludge retains phosphates in the ash. When organic sludges are spread on the land the phosphate is adsorbed by the soil minerals and will serve as a nutrient for crops. However, erosion of phosphate-rich soil brings phosphates into surface waters where they can serve as an algal nutrient.

Orthophosphates can be precipitated from secondary effluents by treatment with a number of polyvalent cations. Of these, calcium in the form of lime is the least expensive. The precipitate formed is apatite, $Ca_5OH(PO_4)_3$, properly named hydroxyapatite which is identical with the mineral that forms bones and teeth. This mineral is frequently and erroneously referred to and calculated as tricalcium phosphate, $Ca_3(PO_4)_2$, a substance which does not form in aqueous systems. Phosphate minerals or rock phosphate are predominantly hydroxyapatite with substantial quantities of the isomorphous fluorapatite. Analyses of rock phosphate are referred to in percent bone phosphate of lime (b.p.l.), which has the arbitrary formula of tricalcium phosphate.

Even at a slightly alkaline pH most wastewaters contain enough calcium to be supersaturated with respect to apatite. However, the rate of crystallization is so slow that weeks or months are required to precipitate substantial quantities of phosphates. By raising the pH the rate of precipitation can be greatly accelerated. The most convenient way to do this is to add hydrated lime, $Ca(OH)_2$. At pH 11 calcium carbonate and magnesium hydroxide are precipitated by the same reactions that occur in the cold lime softening of water (Table 1). Magnesium hydroxide forms a gelatinous precipitate which aids in clarification and increases the removal of phosphates. In the absence of a clarifying agent there is danger that some of the colloidal apatite crystals will remain in suspension and redissolve when the effluent is neutralized.

At Lake Tahoe, California, up to 600 mg/l of $Ca(OH)_2$ (= 0 as CaO) are proposed to remove phosphates from secondary effluents(11)(Figure 2). The sludge from lime treatment contains calcium carbonate, magnesium hydroxide, and organic matter in addition to apatite. Magnesium may be leached out and additional calcium carbonate may be

TABLE 1.

LIME CLARIFICATION, RECOVERY AND REUSE

Precipitation

$$5Ca^{++} + 4OH^{-} + 3HPO_4^{=} \longrightarrow Ca_5OH(PO_4)_3 \downarrow + 3H_2O$$

$$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2CaCO_3 \downarrow + 2H_2O$$

$$Mg^{++} + Ca(OH)_2 \longrightarrow Mg(OH)_2 \downarrow + Ca^{++}$$

Recarbonation

$$Ca^{++} + 2OH^{-} + CO_2 + H_2O \longrightarrow CaCO_3 \downarrow + 2H_2O$$

$$Mg(OH)_2 + 2CO_2 \longrightarrow Mg^{++} + 2HCO_3^{-}$$

Recalcination

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

$$Mg(OH)_2 \xrightarrow{\Delta} MgO + H_2O$$

Hydration

$$CaO \cdot MgO + H_2O \longrightarrow MgO + Ca(OH)_2 + \text{heat}$$

precipitated by treatment with CO_2 at pH 9.5, the pH of minimum solubility of calcium in the presence of carbonate. The sludge can be dried and calcined in a lime kiln to produce calcium oxide, magnesium oxide, and essentially unchanged apatite. The calcium oxide can be slaked to calcium hydroxide and used again to precipitate phosphates. Magnesium oxide ordinarily does not slake or hydrate and remains with the inert fraction.

The extent of lime reuse depends on the hardness of the water. In a hard water area in southwestern Ohio lime treatment softens the water, producing more lime than is charged into the process. As a result, the recovered lime must be continuously wasted and might be sold as a low-grade lime. In a soft water area the phosphates remove lime from the process and the apatite can build up in the recycled lime until it reaches a level comparable in strength to a low-grade rock phosphate. As such it may have some market value to defray part of the cost of treatment. Figure 3, based on studies in Cincinnati, compares the analysis of recovered lime sludges after repeated reuse in a hard water area and in an area with a moderately soft water.

At Lake Tahoe the lime will be reused three times before the phosphates and inert substances build up to the point where it must be discarded. At this location there is no market for phosphates and the waste will be dumped. Fortunately, the phosphate in the ash is quite insoluble and will not leach out into water percolating through the dump.

The reuse of lime sludges helps to reduce the cost of phosphate removal, but it does not offer a product which can be sold at a profit. Recovered lime costs nearly as much as commercial lime so the only savings on chemicals are in the freight. The real savings from reuse of lime comes in the reduction of the disposal problem, since lime sludges accumulate rapidly and are difficult to dispose of.

Aluminum, like other trivalent metal ions, hydrolyzes in water to form aluminum hydroxide which adsorbs and precipitates phosphates at a nearly neutral pH. Either alum, $Al_2(SO_4)_3 \cdot XH_2O$, or sodium aluminate, $NaAl(OH)_4$, can be used to form the hydroxide by suitable pH adjustment (Table 2). The exact

TABLE 2.

PHOSPHATE REMOVAL WITH Al^{+3}

Influence of pH on Al^{+3} form

$$Al^{+++} \underset{}{\overset{+\ 3OH^-}{\rightleftharpoons}} \underset{pH\ 7}{Al(OH)_3}\downarrow \overset{+\ OH^-}{\rightleftharpoons} \underset{pH\ 12}{Al(OH)_4}$$
$$\underset{pH\ 3}{}$$

Phosphate Removal

$$2Al(OH)_3 + HPO_4^{=} \longrightarrow AlPO_4 \cdot Al(OH)_3 \downarrow + 2OH^- + H_2O$$

Solubilization

$$3AlPO_4 \cdot Al(OH)_3 \downarrow + 5Ca(OH)_2 + 6NaOH \longrightarrow 6NaAl(OH)_4 + Ca_5(OH)(PO_4)_3 \downarrow$$

chemical form of the aluminum phosphate is not known, but for high removal efficiency an Al to P ratio of two to one is necessary. This corresponds to the formula $Al(OH)_3AlPO_4$, but a polymeric form is more likely. Figure 4, based on the work of Henriksen,[12] shows the percent removal of phosphate by aluminum as a function of mole ratio of Al to P.

Aluminum hydroxide will redissolve at high pH to form aluminate ions. Some of the aluminum phosphate is also dissolved but the phosphate ions can be precipitated by calcium as apatite.[13] Studies are underway at Cincinnati to find the optimum conditions for aluminate recovery. It should be possible to supply a substantial portion of the alkali requirements with lime. Aluminates can be used as a source of aluminum hydroxide for further treatment by neutralizing the alkali. Bicarbonate alkalinity in the wastewater may be sufficient, but in some cases additional acid may be required. If some aluminum is lost with the calcium phosphate, both aluminum and acid can be supplied as alum which carries three equivalents of acidity per mole of aluminum.

Disposal of aluminum hydroxide sludges has been a difficult problem. Sludges rich in organic matter may be difficult to salvage by conversion to aluminate because humic acids will also dissolve. Very small quantities of aluminum hydroxide clog the soil and prevent use of the land for agriculture. Dewatering of aluminum hydroxide is extremely difficult. The only successful method to date has been to freeze the sludge.[14] This removes the free water and gives an alumina that filters like sand. Freezing is, of course, an expensive process. Aluminum hydroxide with adsorbed phosphates is apparently not dissolved in anaerobic digesters according to recent studies by Barth and Ettinger.[15] Incineration of the sludge will produce insoluble aluminum phosphates in the ash.

Iron salts also hydrolyze to gelatinous hydroxides which adsorb phosphates. Ferric phosphate is reduced in anaerobic digesters to ferrous phosphate. If sulfides are present, the less soluble ferrous sulfide precipitates, liberating the phosphate. Ferric hydroxide or the oxide after incineration can be redissolved in acid, but this also dissolves any phosphates. The old Guggenheim process for chemical treatment of sewage with ferric sulfate followed by incineration and recovery of ferric oxide by solution in sulfuric acid[16] was unsuccessful probably because phosphates accumulated with the iron. Unlike aluminum, it is not possible to dissolve ferric hydroxide at high pH's. Iron salts may have utility for removing phosphates where low-cost waste streams containing iron are available, such as acid mine wastes or iron pickle liquors. Incinerated sludge containing iron phosphates would probably not liberate phosphates to leach waters.

Many other polyvalent metals will precipitate phosphates, and some may be recovered by redissolving the precipitate at high or low pH. None of these metals is as cheap as lime, alum, or iron, and high recoveries would be

necessary to justify the use of any other metal to precipitate phosphate.

NITROGEN

Nitrogen compounds represent the second greatest uncontrolled pollutant in municipal wastewaters.(17) All nitrogen compounds are derived from the atmosphere and eventually return to it in the nitrogen cycle. All the biologically significant forms of nitrogen are interconvertible so they should all be reported on a common basis, such as milligrams of ammonia nitrogen (or nitrate nitrogen) per liter. Nitrogen compounds, except N_2 in the atmosphere, stimulate the growth of algae and lead to nuisance conditions. Blue-green algae also have the ability to "fix" nitrogen from the air producing organic nitrogen which then enters the nitrogen cycle. Nitrogen compounds in general are good fertilizers when applied to the land where nitrogen deficiencies frequently limit crop production, but they are bad fertilizers in surface waters if they contribute to excessive growths of algae and weeds.

Organic compounds of nitrogen can be burned to nitrogen gas. Organic nitrogen compounds are hydrolyzed to ammonia by microorganisms under aerobic or anaerobic conditions. Extended aerobic treatment develops nitrifying bacteria which convert ammonia first to nitrites and then to nitrates. High-rate biological treatment usually leaves most of the nitrogen in the form of ammonia. Extended aeration will convert nearly all of the ammonia to nitrates.(18)

Ammonia is the most common form of nitrogen in wastewaters, averaging about 15 mg/l as N. If these waters are to be reused, the ammonia level must be brought down below 1 mg/l. Chlorination to the breakpoint converts ammonia to nitrogen gas, but 10 mg of chlorine is required per mg of ammonia nitrogen. Breakpoint chlorination of the typical secondary effluent would cost five to ten cents a thousand gallons.

At the pH's of normal secondary effluents, ammonia is present almost entirely as ammonium ions. Above pH 10 nearly all of the ammonia is present as the dissolved gas. Aeration can remove gaseous ammonia from water but the equilibrium is very strongly in favor of the water phase. About 300 cubic feet of air are required per gallon of water at room temperature and an initial pH of 10.8, according to studies at Lake Tahoe. Here the high pH will be obtained by lime treatment to remove phosphates, and air stripping will be carried out in large cooling towers. The cost of air stripping is estimated to be under 2 cents a thousand gallons.(11)

The large volumes of air necessary to remove ammonia make a preconcentration step desirable. Some zeolite minerals selectively adsorb ammonium ions in preference to sodium, calcium, and magnesium ions.(19) Battelle-Northwest is currently investigating the utility of a natural zeolite for adsorption of ammonium ions from wastewaters. Regeneration by lime and aeration of a few percent of the total volume to remove ammonia appears to be feasible. Ammonia levels in air from stripping towers will be extremely low (micrograms per liter) and comparable with nitrate nitrogen from electrical discharges in the atmosphere. Ammonia in the air is eventually adsorbed by soils and surface waters.

Ammonium ions applied to soils are adsorbed by soil minerals including natural zeolites and clay. The adsorbed ammonium ions are available to growing plants. Excess ammonia is converted by soil bacteria to nitrates by the same route that exists in extended aeration. Nitrate ions are also utilized by growing plants but are not adsorbed on soil minerals. Excess nitrates will be leached out of soils producing nitrates in ground water or crystals of saltpeter in caves and cellars.

The Public Health Service Drinking Water Standards (1962) set a limit of 10 mg/l as N for nitrates in water. Higher levels are toxic to infants causing methemoglobinemia or "blue babies," although children and adults can handle large quantities of nitrates without difficulty. Nitrates in surface waters are algal nutrients, not significantly different from ammonia on a nitrogen basis. Nitrates, however, are denitrified by many species of microorganisms in the presence of BOD if oxygen levels are low. The oxygen in the NO_3^- is utilized by the organisms and the nitrogen is liberated as nitrogen gas. Nitrates can thus be a favorable factor in heavily polluted surface waters, whereas they are detrimental in clean waters.

Denitrification by microorganisms is a useful route for ultimate disposal of nitrogen. Several schemes involving

activated sludge have been proposed for denitrification. One system being studied at Pomona, California, involves growing microorganisms on carbon columns to denitrify water, using added methanol as a food source.(20)

SULFUR

In wastewaters, sulfur occurs primarily as sulfates derived from tap water. Sulfates are not considered to be pollutants except as they contribute to total dissolved solids. Sulfates are reduced to sulfides in anaerobic digesters and can be precipitated by metals, especially iron which forms slightly soluble ferrous sulfide. When sludge containing sulfides is burned the sulfur will be released as oxides of sulfur and might produce an air pollution problem. Soluble sulfides, including ferrous sulfide, will precipitate heavy metals except chromium and can remove them from the system. For this reason it has been suggested that sulfates be fed to digesters to prevent poisoning by heavy metals, especially copper and zinc.(21) Sulfides are possible precipitants for mercury, silver, arsenic, and lead as well, but liberation of the metal under oxidizing conditions must be considered.

Any form of reduced sulfur, as well as sulfate salts of ammonia and organic cations, will liberate oxides of sulfur upon incineration. Sulfur concentrations up to 2 percent in digested sludge on a dry solids basis make this fuel as bad as many grades of coal from an air pollution point of view. One way of controlling pollution from sulfur in fuels is to supply calcium and magnesium oxides to the combustion zone.(22) It is quite possible that additions of lime, waste lime sludges, or even ground limestone or dolomite added to the sludge would control sulfur oxide emissions from incinerators. Much will depend on the design of the incinerator. Furnaces for burning the black liquor from kraft paper production successfully control sulfur losses when burning sodium sulfide and organic matter dissolved from wood.

SOLUBLE SALTS

The only acceptable sites for disposal of salts in solution are to the ocean or to salt lakes. Concentrate flows from advanced waste treatment processes such as reverse osmosis, electrodialysis, ion exchange, or distillation will ordinarily not be concentrated more than tenfold and will contain 5000 to 15,000 mg/l TDS. This is still much more dilute than seawater which contains 35,000 mg/l TDS. Further concentration precipitates scale on membranes and heat transfer surfaces. Calcium carbonate comes out first, followed by calcium phosphates. Scale from these two can be controlled by addition of sufficient acid to neutralize the alkalinity or by previous lime treatment of the water. The next scale to come down will probably be a form of calcium sulfate. These precipitates form slowly and may continue to form scale for days. Magnesium chloride hydrolyzes in hot water to form insoluble magnesium oxychloride, liberating HCl. Scale formation and slow equilibrium of precipitates cause least trouble in solar evaporation ponds. Fortunately, many water-short inland areas, where desalting techniques will be required, also are arid areas with low-cost land where solar evaporation ponds can be used. Submerged combustion evaporates water without involving any solid heat transfer surfaces and may be used where solar evaporation is impractical. Scaling problems need not be insuperable even for high-efficiency multiple effect evaporators. Again, the experience of the kraft pulping industry shows that salt solutions containing organics can be concentrated to 50 percent solids on a continuous basis.

Borates in sewage are derived from cleaning compounds, especially perborates used in solid bleaches. Borates have low toxicity to animals and microorganisms and do not present a problem in drinking water. However, many agricultural crops, especially fruit trees, are poisoned by less than one mg/l of boron. There is currently no satisfactory method for removing borates from irrigation water. Borates will stay with the dissolved salts in desalting processes and will have to be disposed of as a salt brine.

Trace elements may occur in municipal wastewaters from spillage corrosion, and as intentional additives to cleaning and processing compounds. Many metals form insoluble hydroxides or carbonates, or are strongly adsorbed on organic matter and are collected in primary or secondary sludges. Oxidation

may liberate these metals, producing toxic flue gases or poisoning soils. Heavy metals, cyanides, selenium, and arsenic are all so toxic and so difficult to deal with in dilute solution that they should be controlled at the source and not be permitted to enter municipal sewers.

SUMMARY

The intelligent disposal of wastes can only be accomplished by a systematic study of the chemistry of the substances involved. Under appropriate conditions wastes can be disposed of economically on or under the land, into the oceans or into the air, but in every case precautions must be taken to control pollution.

The major part of the cost of disposing of sludges and brines is associated with the water content. Costs of dewatering and drying are so high that pipeline transport of wet sludges into the ocean or onto the land is economically attractive.

Organic wastes will be oxidized, either by microorganisms in the water or on the land, or by heat in an incinerator to CO_2. Phosphates must be removed as calcium, aluminum, or iron precipitates. Calcium may be recovered as reburned lime and aluminum as aluminates. In these recovery processes the phosphate eventually comes out as apatite, the natural calcium phosphate mineral which has low solubility in ground water, but is a potential raw material for fertilizer production.

Nitrogen compounds are converted to nitrogen gas by incineration or biological denitrification. Ammonia can be blown off at high pH or can be adsorbed on soil minerals. Sulfur in a reduced form is a potential source of air pollution when sludges are incinerated, but it can be used as sulfides to control heavy metals in digesters. Soluble salts must either go to the sea, to salt lakes, or salty aquifers under the ground.

In every wastewater purification scheme it is necessary to look beyond the initial purification process, be it activated sludge, alum clarification, or reverse osmosis, to include the ultimate disposal of the pollutants in the total costs.

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